A HYPERSPECTRAL IMAGING DEVICE BASED ON A FABRY-PEROT INTERFEROMETER

M. Zucco and M. Pisani
Istituto Nazionale di Ricerca Metrologica (INRIM)
Strada delle Cacce 91, 10135, Torino, Italy

Abstract

A compact hyperspectral imaging device based on a Fabry-Perot interferometer inserted in a digital imaging system is presented. The spectrum associated to each pixel is calculated from the interferogram obtained by scanning the cavity length. Compared to other hyperspectral devices, this device does not make use of mechanical scanning systems allowing the realization of more compact product that could be easily integrated in existing optical systems. Further advantages are the high numerical aperture and the high transmissivity.

Introduction

A hyperspectral system is a combination of an imaging device (a digital camera) and a photospectrometer. It generates a data “cube” where a 2D image is combined with a third dimension giving the spectral composition of each pixel of the same image. Hyperspectral devices are commonly made by integrating a dispersive mean (a prism or a grating) in an optical system including a mechanical scanning system. An alternative method to obtain the spectrum of a light source, is the so called Fourier transform spectroscopy [1]; here the Fourier transform is applied to the interferogram acquired by a scanning Michelson interferometer. This technique is difficult to integrate in an optical system because of its limited numerical aperture. Here we propose the use of a Fabry-Perot (FP) interferometer to obtain a hyperspectral image.

Fabry and Perot realized the multiple-beam interferometer at the end of 19th century and used it for metrology, spectroscopy, and astrophysics applications [2]. Considering a cavity formed by two partial reflecting mirrors, the transmitted intensity is proportional to the Airy function (1), where R is the mirror reflectivity and δ is the optical path that includes the penetration depth in the metallic layer of the mirrors.

$$I_t \propto \frac{1}{1+\frac{4R}{(1-R)^2}\sin^2\left(\frac{\delta}{2}\right)} \qquad (1)$$

Varying the distance between the mirrors, an interferogram is obtained with substantial differences with respect to the one acquired from Michelson interferometer. First, the interferogram is single-sided and it does not start from the central or zero fringe, this fact is due to the metallic penetration depth which has been verified to be constant in the considered spectral interval at the required uncertainty level. Second, the Fourier transform of the Fabry-Perot interferogram generates the harmonics of the spectrum. These problems are solved using suitable bandpass optical filters together with a fitting software. This limits the spectral analysis to one octave range.

Results

The considered imaging spectrometer is formed by two aluminized mirrors mounted in a frame that slightly bends the mirror surfaces in order to prevent optical bonding when they are in contact. The distance between the mirrors is varied by means of three piezoelectric actuators, allowing a maximum range of approximately 20 μm corresponding to a resolution of about 7 THz, equivalent to 8 nm at 600 nm. The calibration of the actuator driving voltage is carried out by counting fringes in the frames when the scene is illuminated by laser light. The sensor is a commercial 8-bit VGA CCD camera. In figure 1, the spectra obtained from the captured video of a sample made from a Gretag Macbeth® Color Checker® are shown. The spectra are normalized to the white sample present on the target. Good correspondence between measured spectra and reference spectra measured with a commercial spectrometer are obtained.

In a second application, a target combining different sources (green, yellow, red, blue, white LEDs, white lamps and spots shone with a green laser) has been captured. Differently from the previous case, in order to calculate an emissivity spectrum, the spectral responses of the optical system and of the camera have to be taken into account. In figure 2, calculated spectra of the yellow and red LEDs are compared with the reference spectra.

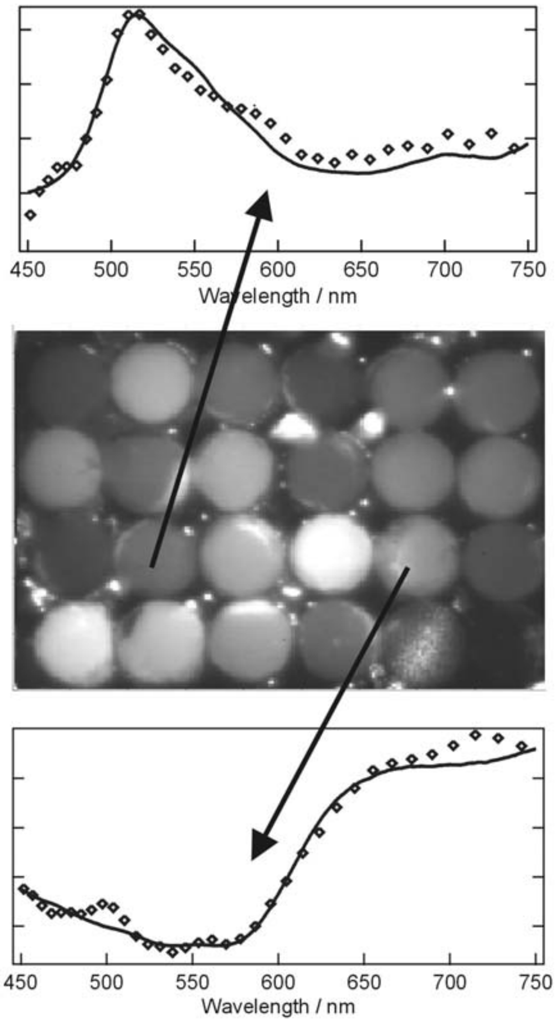

Figure 1. Each pixel of the hyperspectral image (in the middle) contains the spectral composition of the reflected light. At the top (bottom) the measured spectrum in diamond of the green (red) normalized to the Macbeth white is plotted against the reference spectrum in solid line.

Conclusions

A compact hyperspectral imaging device based on a Fabry-Perot interferometer inserted in a digital imaging system is presented. One octave spectra are calculated from the interferogram obtained from a scene capture. The system promises high speed, high numerical aperture hyperspectral imaging without mechanical scanning.

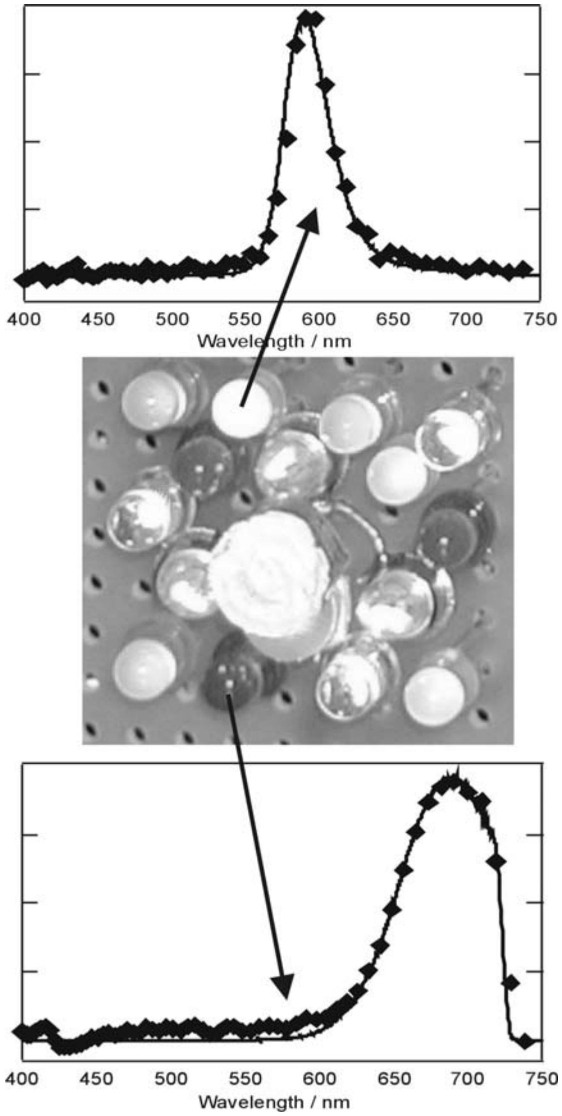

Figure 2. In the middle picture, the image of target formed by different LEDs, lamps and laser spots. At the top (bottom) the measured spectrum in diamond of the absolute emissivity spectrum of the yellow (red) LED compensated for the spectral response of the optical system, plotted against the reference spectrum in solid line

References

[1] A. A. Michelson, "On the Application of Interference Methods to Spectroscopic Measurements." *Phil. Mag*. 34, 280, 1892.

[2] C. Fabry and A. Perot, "Sur les franges des lames minces argentées et leur application à la mesure de petites épaisseurs d’air", *Ann. Chim. Phys.* , vol. 12, pp. 459-501, 1897.